

## Tribology of Composite Au-MoS<sub>2</sub> Films at Varying Contact Stresses

1 June 2003

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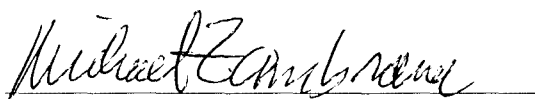
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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

A handwritten signature in cursive script, reading "Michael Zambrana", is written over a horizontal line.

Michael Zambrana  
SMC/AXE

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14. ABSTRACT  Solid-lubricant coatings for sliding electrical contact applications like slip-ring assemblies have very different requirements from typical applications like ball bearings and cutting tools: they have significantly lower contact stresses and sliding speeds. We are optimizing the performance of sputter-deposited nanocomposite Au-MoS <sub>2</sub> films for such low contact stress applications. Higher contact stress pin-on-disk tests ( $S_m = 730$ MPa) showed that low Au-MoS <sub>2</sub> films (i.e., 22 to 38 at% Au) outperformed those with higher Au content (i.e., $\geq 55$ at% Au). In contrast, low contact stress disk-on-disk tests ( $S_m \sim 0.3$ MPa) showed that higher Au-content films outperformed low Au-MoS <sub>2</sub> films. These results, along with Auger Nanoprobe post-test analysis, indicate that Au provides structural integrity for the films in the high-contact-stress tests, while optimizing the MoS <sub>2</sub> transfer rate in the low-contact-stress tests. The results are promising for sliding electrical contacts because high-Au films not only perform the best tribologically, but also exhibit the highest electrical conductivity.					
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# **Tribology of Composite Au-MoS<sub>2</sub> Films at Varying Contact Stresses**

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**1 May 2003**

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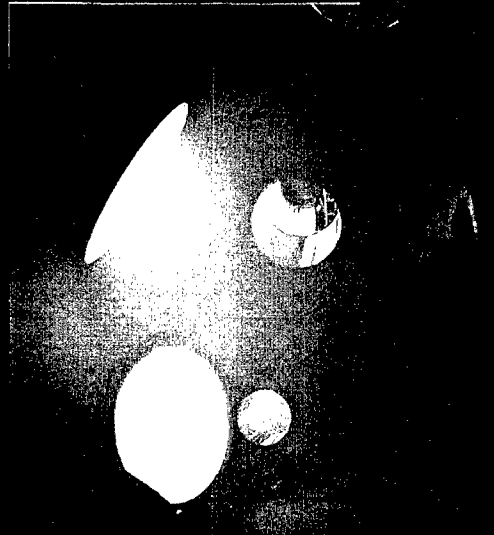
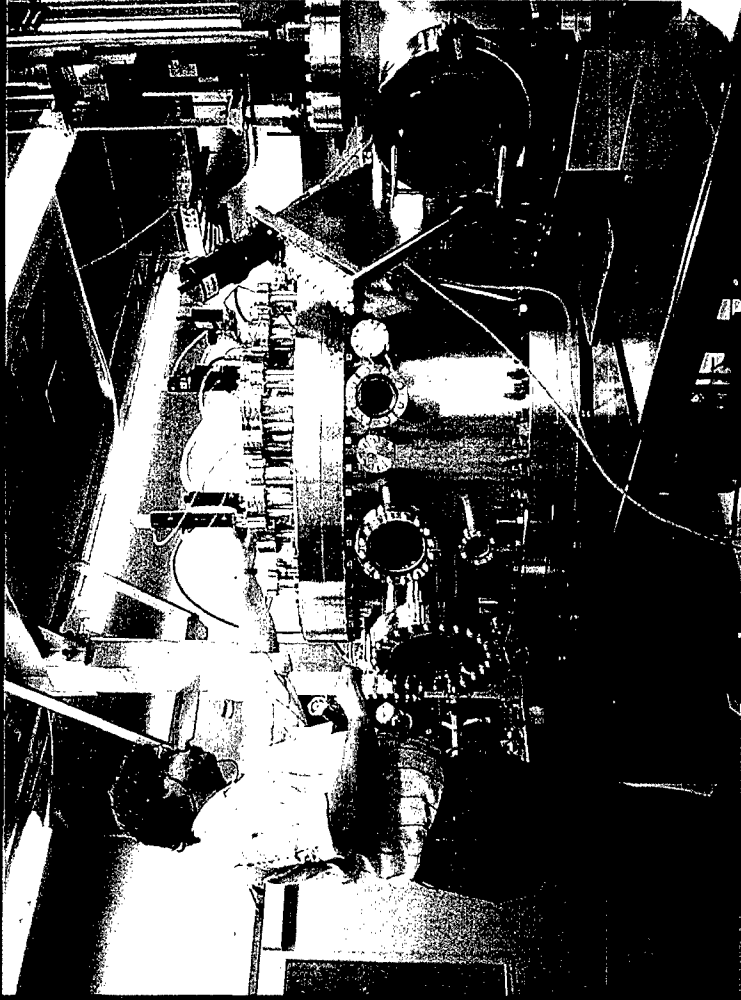
# Outline

- Background
- Description of Apparatus
  - Multitarget rf magnetron sputter deposition system: Au, MoS<sub>2</sub>
  - CS(E)M Tribometer; Purged with purified N<sub>2</sub>
  - Auger Nanoprobe
- Friction Testing
  - Testing at two contact stresses for 2000m
  - Pin-on-disk (only disk coated): 730 MPa (106 ksi) mean Hertzian stress
  - Disk-on-disk (only one disk coated): ~0.1 MPa (15 psi) mean Hertzian stress
- Analysis of Wear Track/ Transfer Films: Auger Nanoprobe
- Summary/ What's Next

## Background

- Sputter-deposited MoS<sub>2</sub> films used in space and ground applications are generally moderately high contact stress
  - Actuators (solar array drives), deployment mechanisms, gimbal bearings
  - Cryogenic lubrication applications (Launch vehicle engines)
  - Used increasingly for cutting/forming tools, etc.
- Conductive, lubricious, adherent films could provide a boon for sliding electrical contacts in vacuum (and terrestrial?) environment
  - Slip Rings
  - Switches & Relays
  - Connectors
- Behavior of sputter-deposited MoS<sub>2</sub>-based films at low contact stress not well-characterized: What parameters are important?

# RF Sputter-Deposition System



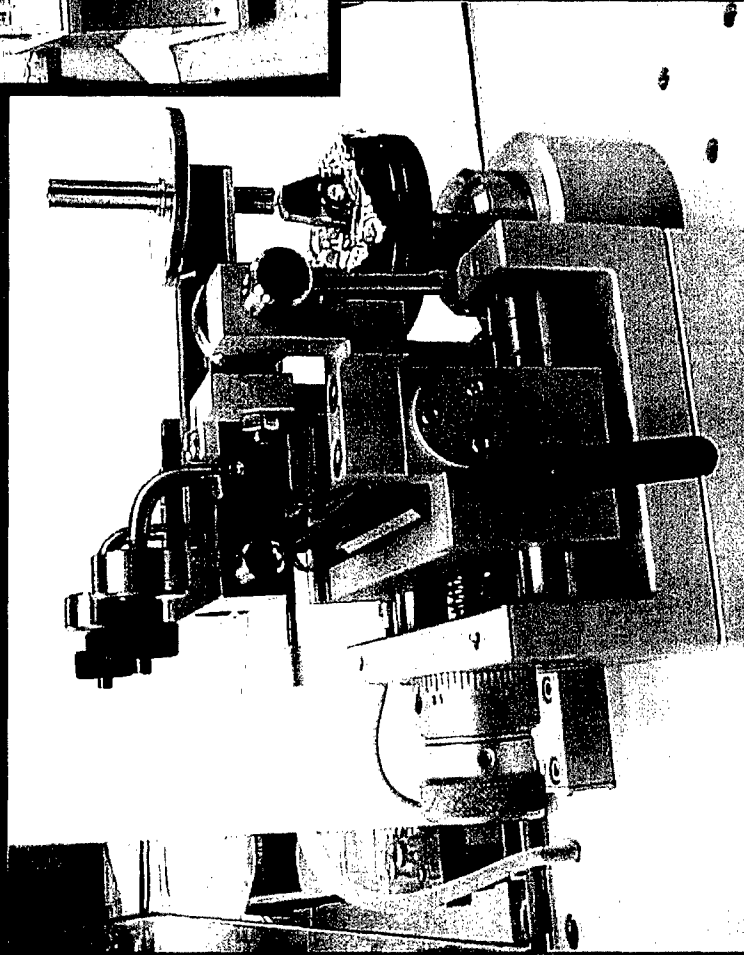
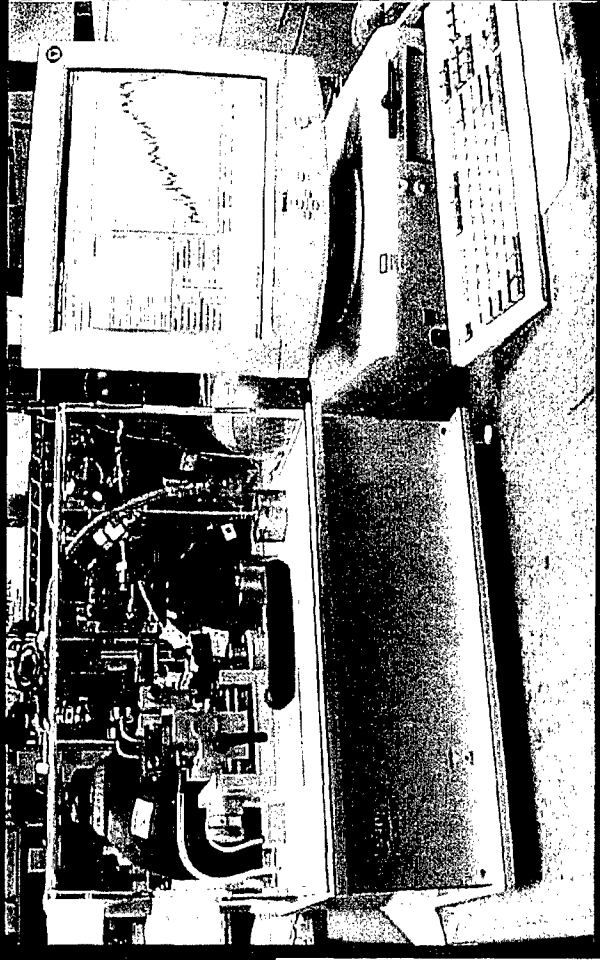
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# CS(E)M Pin-on-Disk Tribometer



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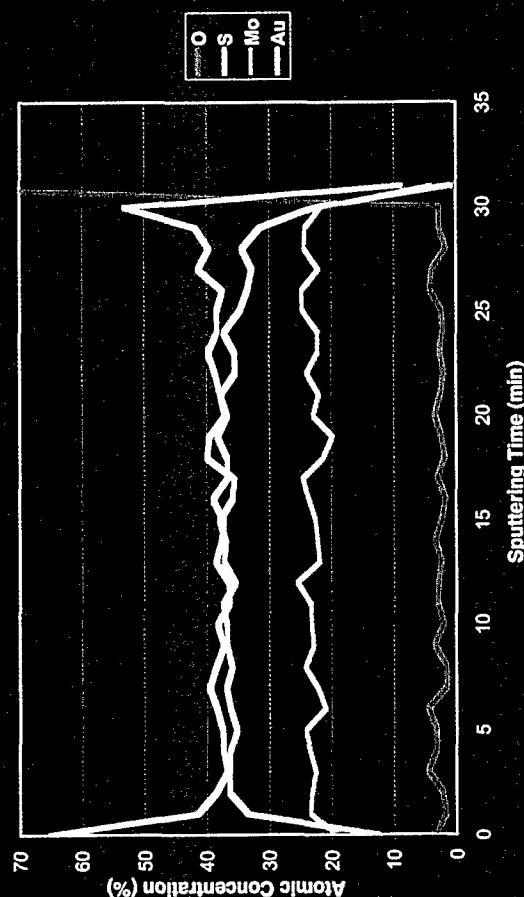
## Experimental Details

- **Sputter-Deposition Thin Film Growth Parameters**
  - Upper and lower specimens are 440C steel
    - Cleaned before deposition/testing in Brulin 815GD/ Heptane
  - Thin film growth chamber base pressure:  $1 \cdot 10^{-9}$  Torr ( $1.33 \cdot 10^{-7}$  Pa)
  - Simultaneous deposition of Au & MoS<sub>2</sub> using RF magnetrons
    - Au: 60-200W (0.7 - 2.0 W/cm<sup>2</sup>) - partially unbalanced
    - MoS<sub>2</sub>: 100-200W (1.2 - 2.0 W/cm<sup>2</sup>)
  - Continuous stream of purified Ar (< 1 ppm H<sub>2</sub>O, O<sub>2</sub>, CO, etc.)
    - Chamber pumped continuously
    - During deposition, Ar pressure  $\approx 3 \cdot 10^{-3}$  Torr (0.4 Pa)
  - Substrate on rotating table during thin film deposition
- **Friction testing under 5 N load, 8 cm/s, 2000 m goal, in purified N<sub>2</sub>**
  - High contact stress, 8mm ball on disk:  $S_m = 730$  MPa (106 ksi)
  - Low contact stress, 0.8 diam flat on disk:  $S_m = \sim 0.1$  MPa (15 psi)
    - Similar to contact stresses in slip ring/brush contacts
- **PHI 680 Nanoprobe with Ar ion gun: Pre-, Post-wear test analysis**

# Auger Depth Profiles of Au-MoS<sub>2</sub> Films

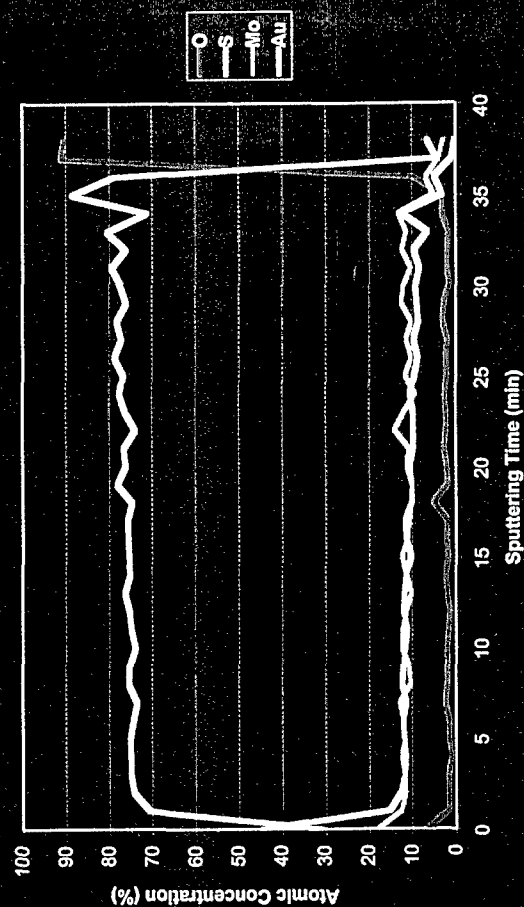
**38% Au/ 62% MoS<sub>2</sub>**

Au/MoS<sub>2</sub> with 38% Au



**76% Au/ 24% MoS<sub>2</sub>**

Au/MoS<sub>2</sub> with 75% Au

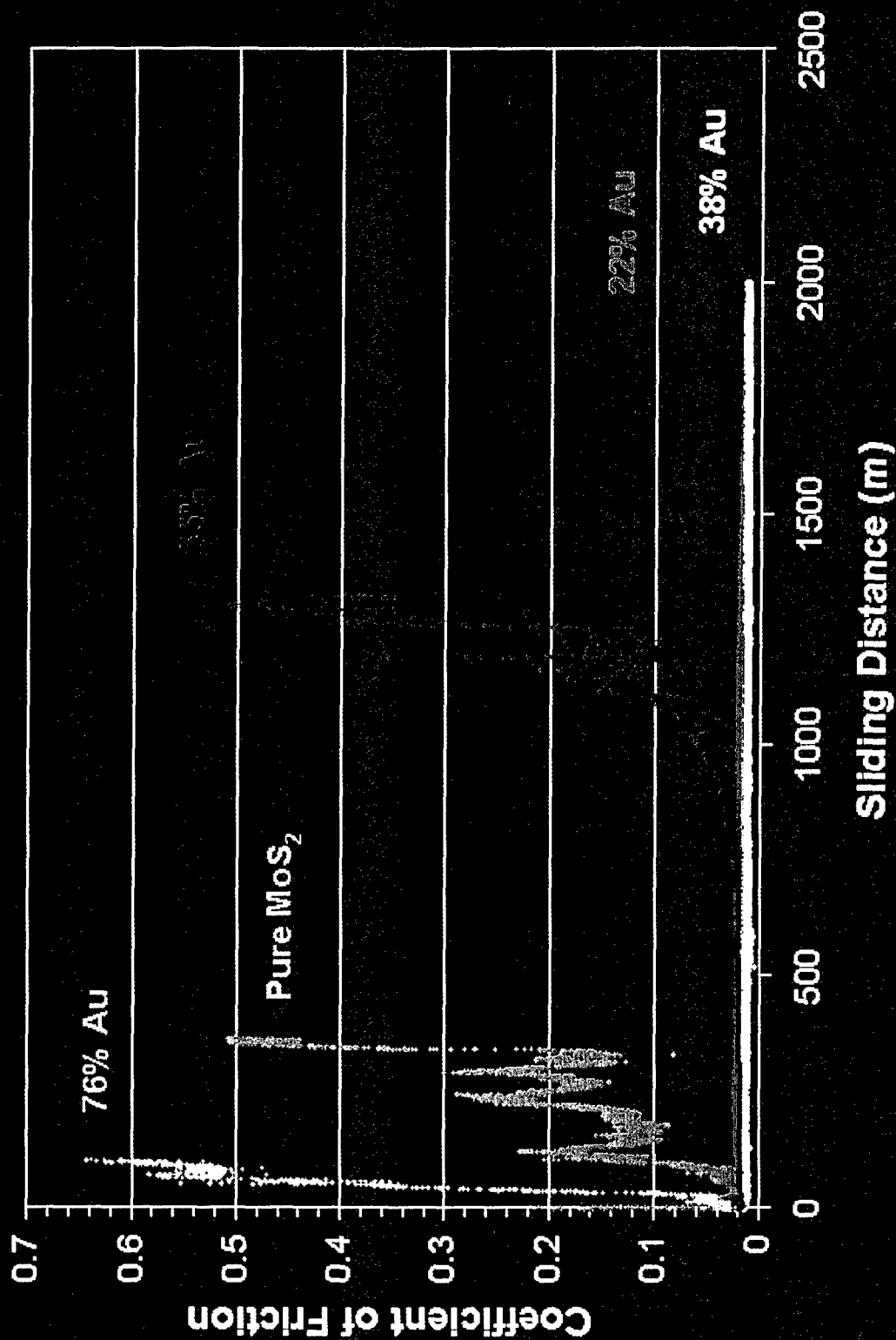


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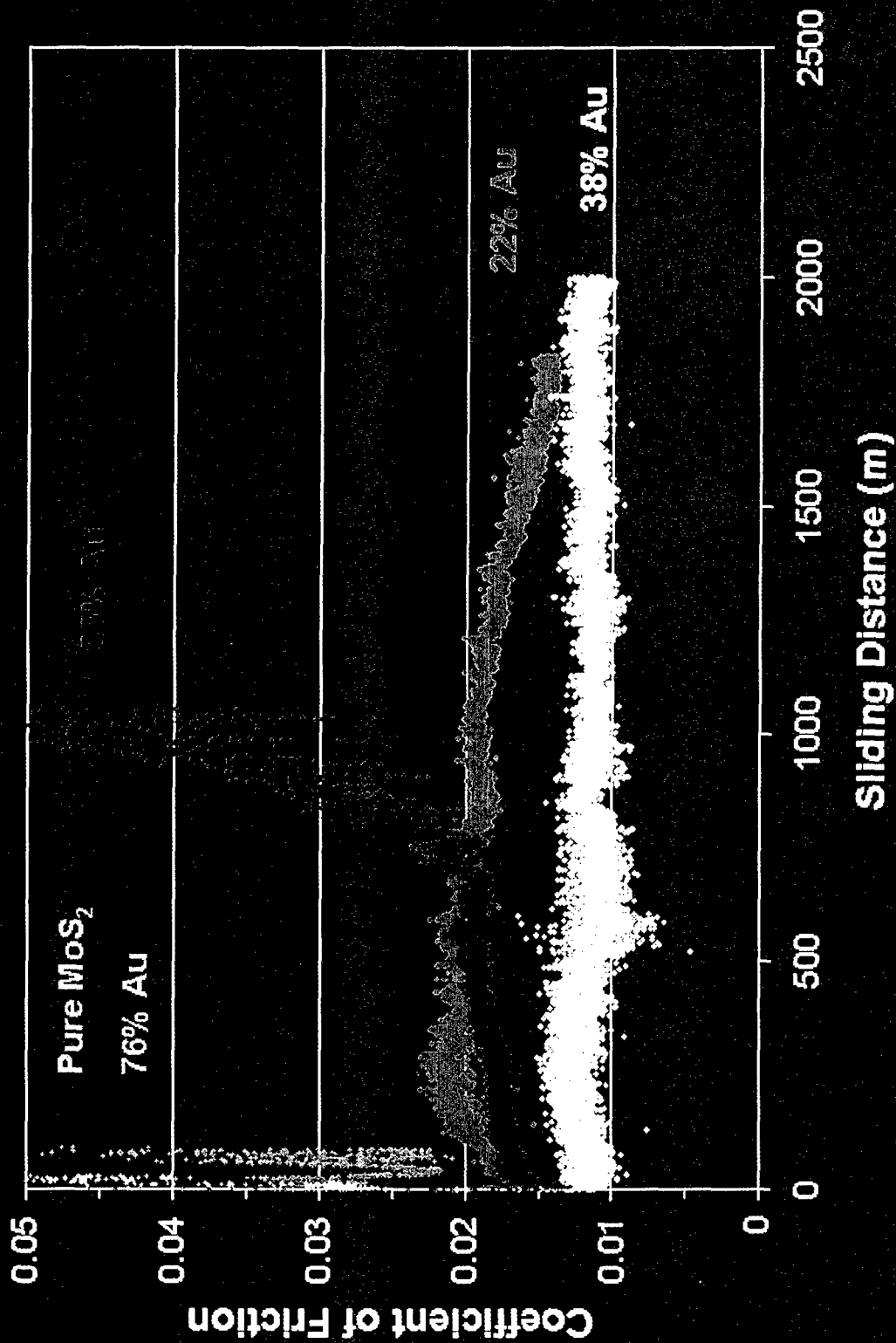
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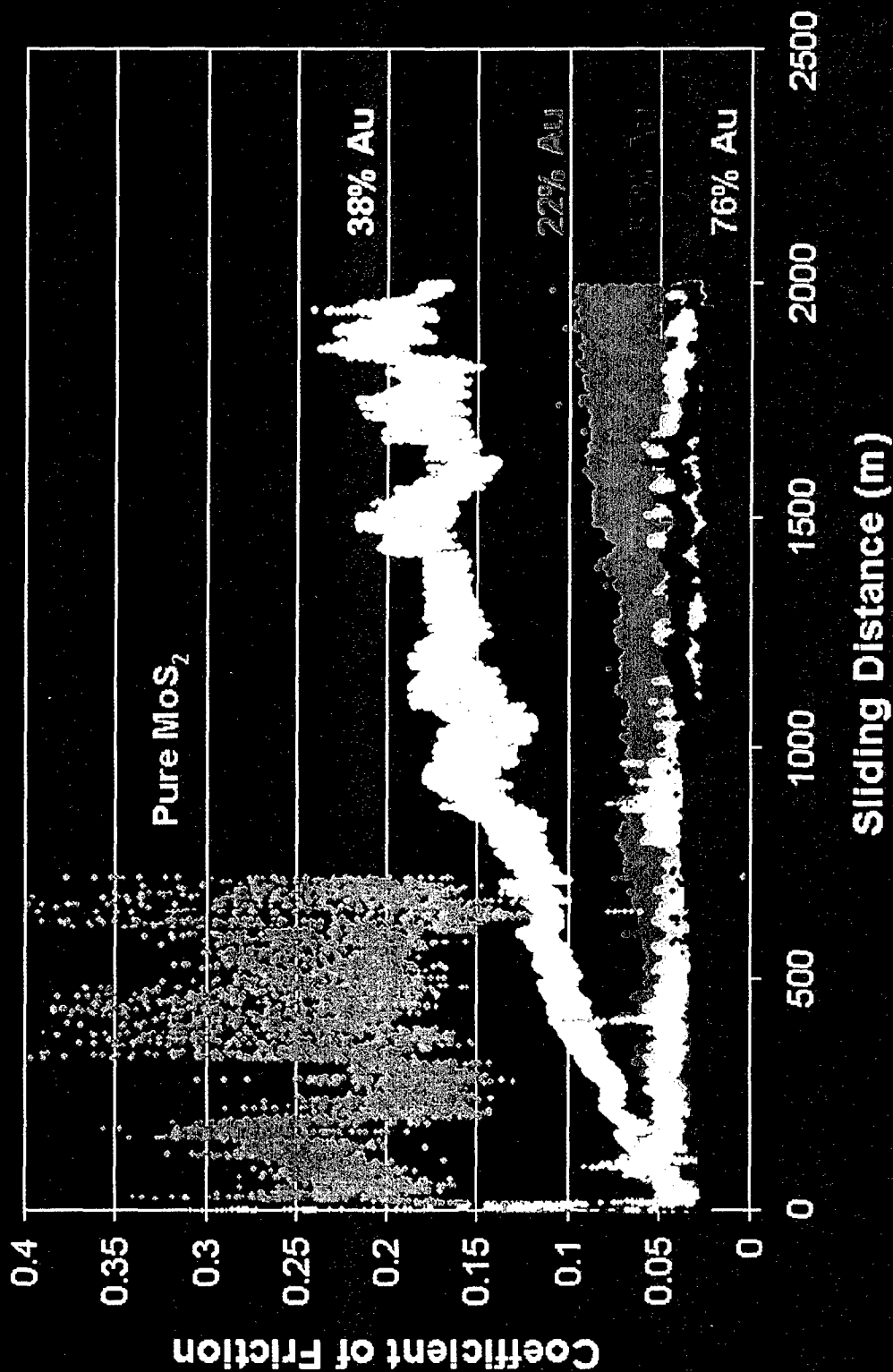
# Friction of Au/MoS<sub>2</sub> Films Tested at High S<sub>m</sub>



# Friction of Au/MoS<sub>2</sub> Films Tested at High S<sub>m</sub>



# Friction of Au/MoS<sub>2</sub> Films Tested at Low S<sub>m</sub>



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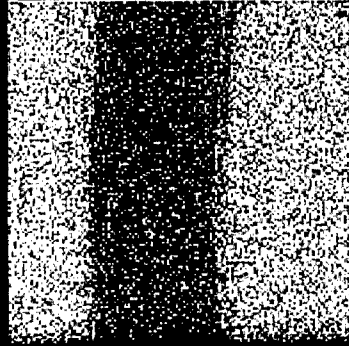
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# Auger Analysis in Wear Track of Au/MoS<sub>2</sub> Film (38% Au) after High S<sub>m</sub> Test

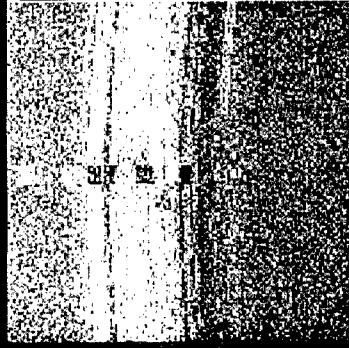


SEM Image

- Thin MoS<sub>2</sub> layer provides lubrication
- Underlying Au/MoS<sub>2</sub> film provides support (wear resistance)
- Detection of MoS<sub>2</sub> on surface of film is typical of Au/MoS<sub>2</sub> films prior to failure

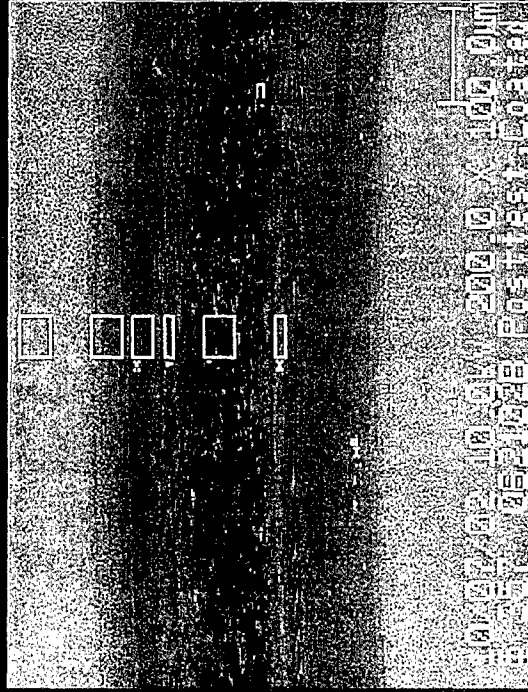


Au Auger Map



S Auger Map

# Wear Tracks on Au/MoS<sub>2</sub> Films after High S<sub>m</sub> Tests



38% Au

- Mostly MoS<sub>2</sub> in track
- Small substrate peak seen only in track center
- Au detected only outside track



76% Au

- Little MoS<sub>2</sub> in track
- Substrate peak seen throughout track
- Au detected only outside track

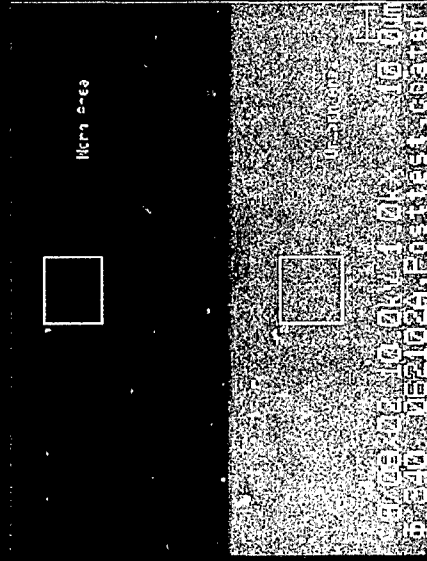
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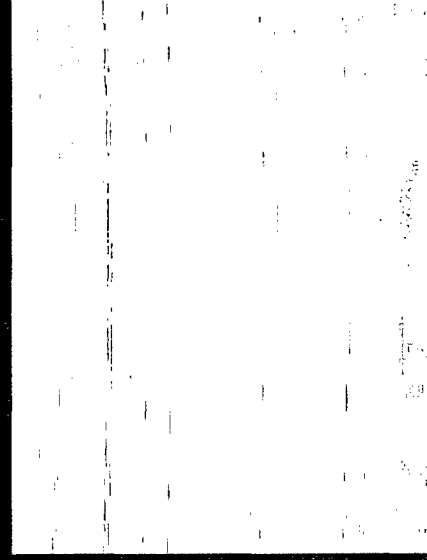
# Auger Analysis in Wear Track of Au/MoS<sub>2</sub> Films after LOW S<sub>m</sub> Test

38% Au

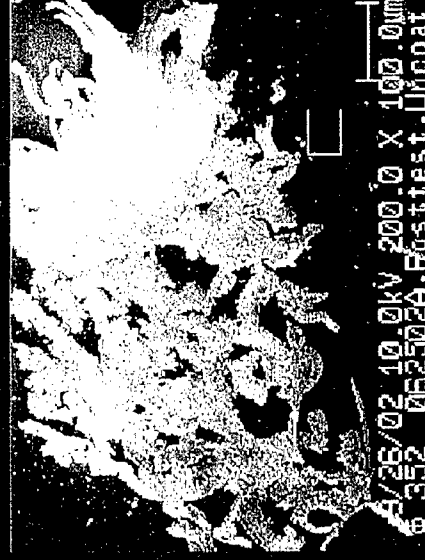
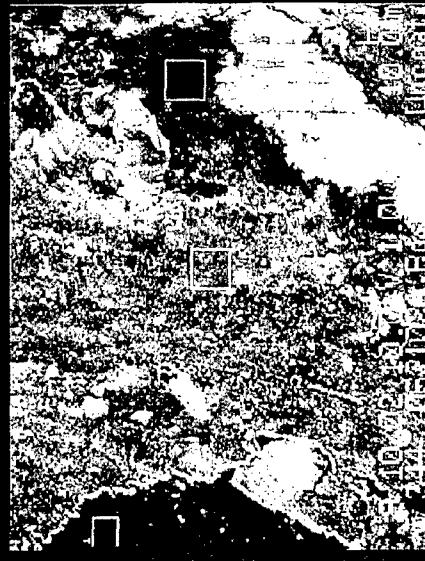


**Coated disks:**  
Auger shows significant MoS<sub>2</sub> remains in the contact region; little Au detected

76% Au



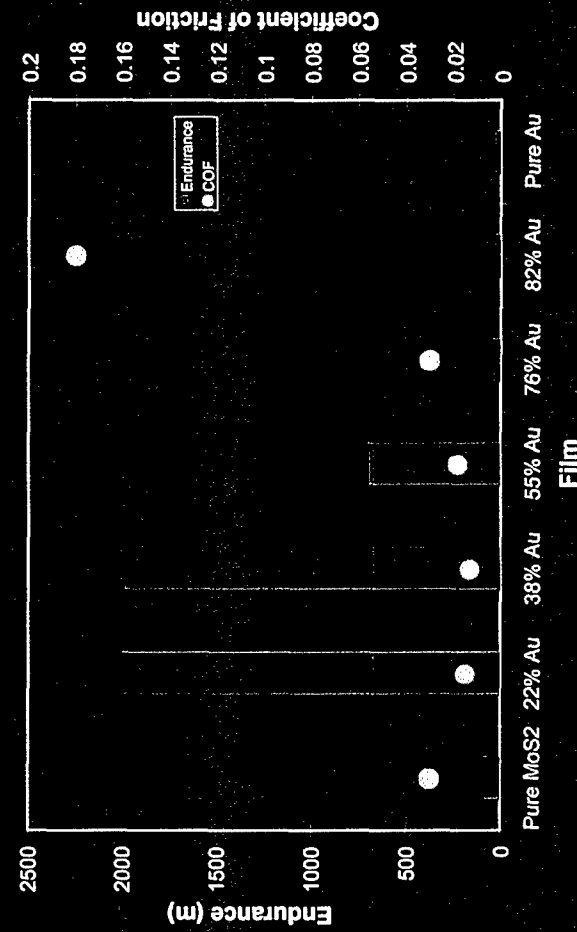
**Uncoated disks:**  
Auger shows that surfaces of transfer films on uncoated disks are mostly MoS<sub>2</sub>



# Summary of Friction/Endurance Testing

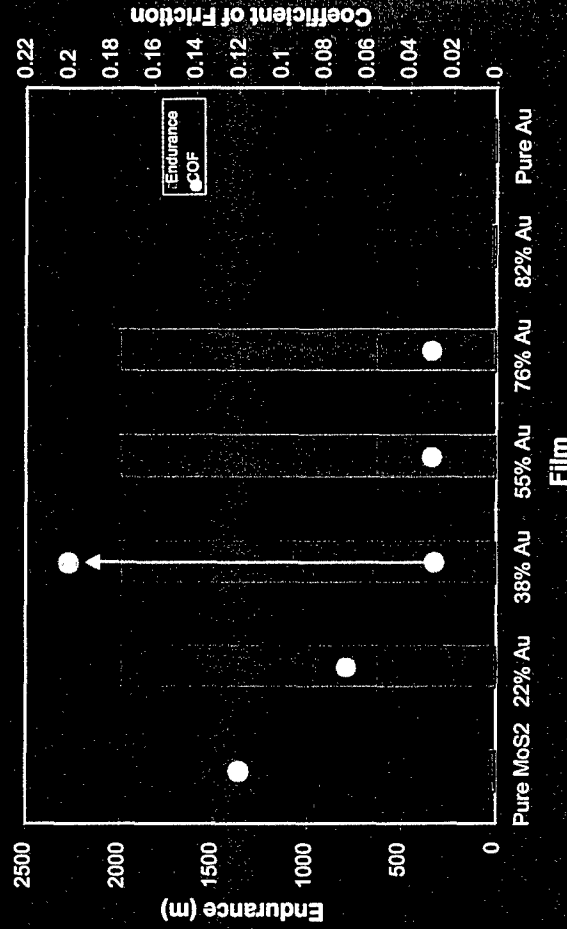
## High Contact Stress

Performance at High Contact Stress



## Low Contact Stress

Performance at Low Contact Stress



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## Discussion

- At high contact stress, sputter-deposited MoS<sub>2</sub>-based films work best in conditions that:
  - Allow lubricating layer and transfer film that are *thin* and *uniform*
  - Subsurface (unworn) part of film is fracture-tough
- E.g., previous Aerospace studies varying gaseous test ambient
  - Oxygen improves transfer film formation
  - Water causes thick, uneven transfer film formation
- High contact stress; allows MoS<sub>2</sub> to shear
  - Low metal: dense, hard, fracture tough, environmentally stable films
  - High metal: soft films, high wear
  - No metal: high wear
- Low contact stress; does not allow MoS<sub>2</sub> to shear as readily
  - High metal: limits transfer of lubricant
  - Low or No metal: excessive lubricant transfer (wear)/ patchiness

## Summary

- Testing at *high* contact stress ( $S_m = 730$  MPa or 106 ksi) up to 2000 m
  - Low friction (0.01 to 0.02) throughout test for films with 22%-38% Au
  - Low friction (0.02), but limited endurance for film with 55% Au
  - Low endurance for films with 76%-82% Au, pure Au, and pure  $\text{MoS}_2$
- Testing at *low* contact stress ( $S_m = \sim 0.1$  MPa or 15 psi) up to 2000 m
  - Lowest friction (0.03) for films with 55% and 76% Au
  - Higher (and increasing) friction (0.07 to 0.2) for films with 22%-38% Au
  - Rapid failure for film with 82% Au, pure Au, and pure  $\text{MoS}_2$
- Post-test Auger nanoprobe: Interface lubricated by thin  $\text{MoS}_2$  film
- Best low- $S_m$  performance for high Au content → Best electrical conductivity
- Next studies: Nanohardness, Conductivity, Thickness of lubricating layer, Slip ring tests

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